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COMPARISON OF DIFFERENT METHODS FOR ESTIMATING SNOWCOVER IN FORESTED, MOUNTAINOUS BASINS USING LANDSAT (ERTS) IMAGES

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ABSTRACT

Snow-covered areas on LANDSAT (ERTS) images of the Santiam River basin, Oregon, and other basins in Washington were measured using several operators and methods. Seven methods were used: (1) Snowline tracing followed by measurement with planimeter, (2) mean snowline altitudes determined from many locations, (3) estimates in 2.5 x 2.5 km boxes of snow-covered area with reference to snow-free images, (4) single radiance-threshold level for entire basin, (5) radiance-threshold setting locally edited by reference to altitude contours and other images, (6) two-band color-sensitive extraction locally edited as in (5), and (7) digital (spectral) pattern recognition techniques. Methods (4), (5), and (6) used the SRI Electronic Satellite Image Analysis Console (ESIAC). The seven methods are compared in regard to speed of measurement, precision, the ability to recognize snow in deep shadow or in trees, relative cost, and whether useful supplemental data (such as the distribution of snow-covered area with location or altitude) are produced. Standard errors range from about 3 to over 12 percent of the basin area depending on method and the fraction of the basin which is snow covered.

INTRODUCTION

The areal extent of snow in forested, mountainous drainage basins is difficult to measure with sensors flown in high-flying aircraft or satellites, and the cost of accurate measurements is extremely high with sensors at ground level or in low-altitude aircraft. Thus evaluation of satellite techniques for measuring snow in large, forested mountain basins is beset by both difficult (or subjective) methodologies and a general lack of accurate field data for comparison. Satellite snow measurements for drainage basins in the Cascades of Oregon and Washington are especially difficult for the basins contain large areas of virtually complete forest canopy, steep slopes with great radiance contrasts between sunlit and shadowed areas, and frequent cloud cover. Yet it is in basins such as these that the need for data

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is most critical because of the importance of snowmelt forecasts for the optimal operation of a large number of hydroelectric power and irrigation reservoirs.

This paper compares snow measurements from LANDSAT (ERTS) images of basins in the Oregon and Washington Cascades using seven different measurement techniques and several operators. The measurement techniques are evaluated in terms of their usefulness for repetitive, operational programs. No absolute standard of accuracy exists; even if it had been possible to obtain complete aerial photographic coverage at the time of each satellite overpass, no measurement procedure from these photographs would be free of error. The term precision is used here when evaluating methods. A method which produces consistent, repeatable results from operator to operator, basin to basin, and image to image is said to be precise.

An important difficulty in obtaining precise readings is the subjective judgment of the area of snow obscured by forest canopy. Special attention is given to this problem. In forest openings (clear cuts, transmission-line cuts, natural openings, etc.) the existence or lack of snowcover can be observed. The snowline must then be interpolated between these openings. This interpolation is valid only if the snow observed in openings is representative of the snow in the forest. In spite of much research on this subject (e.g., Anderson and Gleason, 1959; Hoover and Leaf, 1967; Gary, 1974) it is still impossible to know how representative the snow in forest openings is. In some areas including western Oregon more snow than normal may be deposted in openings, but such snow also may melt more rapidly (Rothacher, 1965).

Attention was concentrated on the drainage basin North Santiam River above Detroit Reservoir, Oregon (1,134 km^2), listed here as the Santiam Basin (Figure 1). This is a typical high Cascade basin, with heavy forest, clear cuts, steep slopes, and some high, alpine areas. It is a basin for which snow data are required for reservoir operation, and one of several basins selected in the Pacific Northwest for the Operational Applications of Satellite Snowcover Observations Program. In addition to Santiam Basin images of February 11, April 6, April 24, and May 12, 1973, and June 30, 1974, measurements were also made of images of Thunder Creek, Cascade River, and South Cascade Glacier drainage basins, all in the North Cascades of Washington.

MANUAL METHODS

LANDSAT (ERTS) band 5 (0.6 to 0.7 μm wavelength) provided the best separation of snow from other materials, and was used in all of the three manual methods.

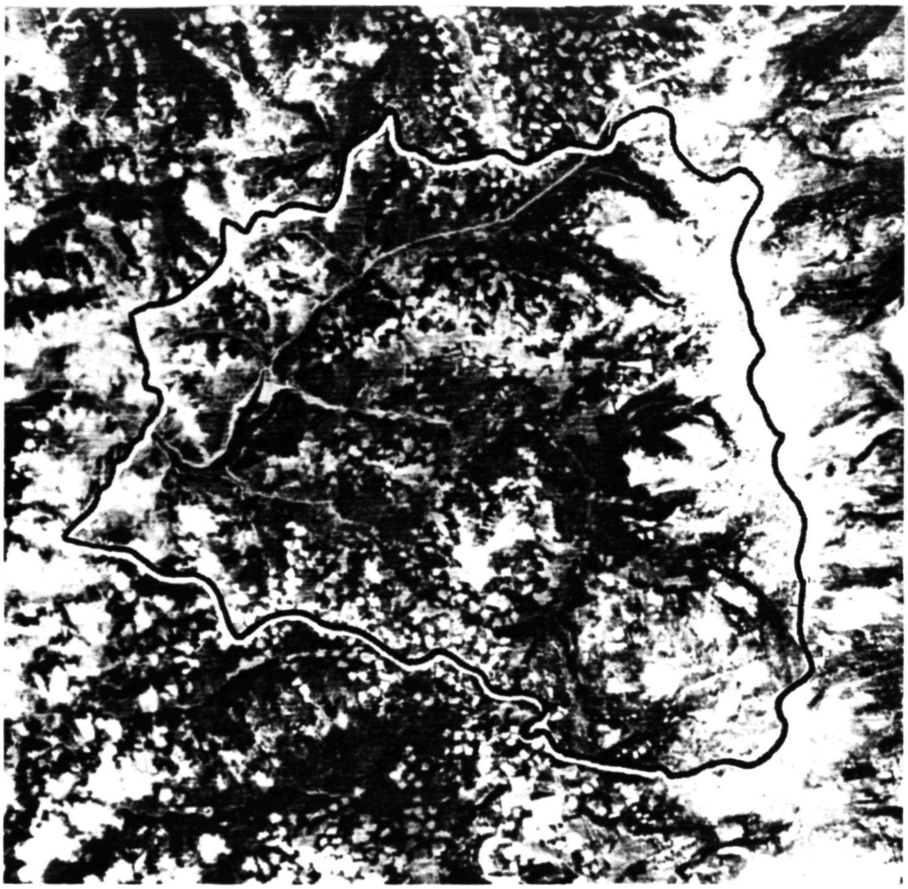

Fig. 1--LANDSAT (ERTS) image of Santiam Basin as of April 6, 1973. Drainage basin is indicated by the black and white line. Note the white snow showing in numerous rectangular clear cuts in the dense forest, and the grey non-snow conditions showing in other clear cuts.

Method 1: Snowline tracing and measurement with planimeter

This technique, in several variations, has been widely used and is well described elsewhere (Barnes and Bowley, 1974). The snowline and drainage basin outline can either be traced directly on an enlarged image or on a transparent overlay, or transferred to a map using a transparent, gridded overlay or an optical device such as a zoom transfer scope. The method is relatively time-consuming if the snow boundary is deeply convoluted and patchy and if the observer tries to follow the snowline carefully. Other desired information such as altitude contours or time-lapse sequences is rarely available so that snowline interpolation is

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very subjective. This difficulty plus the inherent errors in measuring the area of a deeply convoluted curve make the method relatively imprecise. Standard deviations about group means of individual operator determinations using drainage basins in the North Cascades ranged from 7 to 11 percent during the melt season, and up to 32 percent in winter.

Method 2: Mean snowline altitudes determined from many locations

This technique is useful in mountainous regions because the snowpack generally varies strongly with altitude but only slightly with horizontal distance. The general technique has been used by many. In this study operators were asked to scan enlarged LANDSAT (ERTS) images (1:250,000) of the Santiam Basin for areas where the snowline was clearly defined, and then to interpolate the altitude from a transparent overlay with 152.4 m (500 ft) topographic contours. Each such determination was punched into a simple statistical routine on a pocket calculator. The operator then scanned for additional points, attempting to cover the basin uniformly, and continued until the number of points measured (as displayed on the calculator) totalled at least 20. The mean altitude and standard deviation were then calculated, and converted to equivalent area through use of an area-altitude curve.

This method is extremely fast (requiring 2-5 minutes per image), requires little expensive equipment, and is relatively precise. The standard deviation of individual operator's results from the 5-operator mean ranged from 81 to 178 m (average 126 m) in altitude, corresponding to 2.4 to 5.3 percent (average 3.8 percent) of basin area.

Method 3: Estimates in 2.5 x 2.5 km boxes with reference to a snow-free image

This technique was first exploited by Lauer and Draeger (1974), who used squares (boxes) 1.98 x 1.98 km in size. We chose 2.5 km as a convenient grid size--small enough so that major drainage basins would be adequately sampled yet large enough to contain adequate information (about 1500 resolution elements or pixels) for snowcover estimations. This box size was also convenient to index to the UTM metric grid printed on topographic maps.

Operators were provided with a 1:250,000 LANDSAT (ERTS) image, a transparent overlay showing the 2.5 x 2.5 km boxes together with some drainage information for registering to the image, a transparent overlay with topographic contours for reference, a late-summer color-IR composite image also for reference, and a set of rules for interpolating the snowline between known positions. The operator then marked the snowcover in tenths in each box, copied the result, computed the mean snow area (percent of basin area) and some statistical parameters, and cleaned the overlay for the next measurement.

This method is not as fast as (2); careful work required at least 15-30 minutes per determination for the Santiam Basin. It is relatively precise; standard deviations of individual operator's results from the operator means ranged from 3.3 to 12.2 (average 5.9) percent of the basin area.

The method was also tested using a single color image (May 12, 1973) and two operators. Both operators measured less snow on the color image (average 11.1 percent snow) than on the black and white, band 5 image (average 14.1 percent). The information content of the color image is higher, so this suggests that the box method using a black and white enlargement may slightly bias the results. The cost and time involved in making color enlargements makes it impractical to use them in an operational program.

METHODS USING AN ELECTRONIC, INTERACTIVE ANALYZER

The Stanford Research Institute's Electronic Satellite Image Analysis Console (ESIAC) is an interactive instrument that employs television scanning, storage, and animation techniques in a manner intended to bridge the gap between traditional photo-interpretation and completely objective digital processing (Evans, 1973). It has a sequential image capability which permits rapid registration, storage and retrieval of up to several hundred TV frames. Thus time-lapse sequences can be produced, and the superposition of overlays, drainage basin maps and elevation contours can be handled efficiently. Capability for manual editing and quantitative measurement of pixel radiance is also provided. While digital tapes can be accommodated, input normally has been from film transparencies.

To make quantitative measurements of the areal extent of scene constituents with the ESIAC, the general procedure is to create a binary thematic map, or "mask", from the source imagery. This mask is maintained in revisable "scratch-pad" memory, and is displayed as a two-dimensional image that can be viewed alone or in superposition with the full-tone scene images. The binary mask may also be written on the disc file of a minicomputer in 2.5 x 2.5 km grid increments. Figure 2 shows a binary mask of the Santiam Basin (May 12, 1973) together with a computer print-out of these same data reduced so that each digit represents tenths of snowcover within each 2.5 x 2.5 km box. This procedure provides a simplified mechanism for machine storage and sorting of the data. In addition, statistical data (e.g., box-by-box means, standard deviations, and residuals) can be derived which may help to identify sources of bias from individual operators and methods.

A number of operating options are possible. Increases in

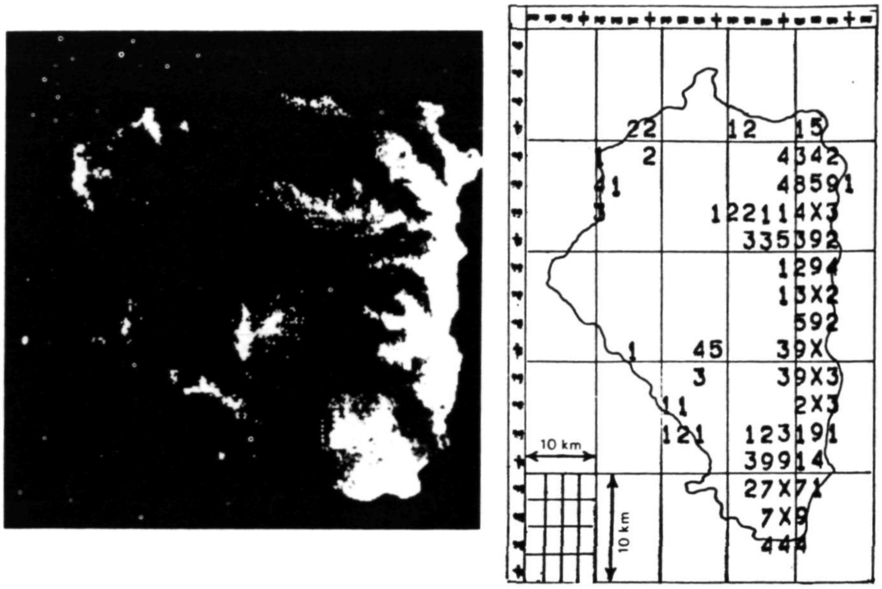

Fig. 2--(Left) Typical binary mask generated by ESIAC of the Santiam Basin, May 12, 1973 image, using a radiance-threshold locally edited by reference to altitude contours. (Right) Computer printout of the data from this mask expressed as snow-covered area (in tenths) in 2.5 x 2.5 km boxes. No snow is blank, complete snowcover indicated by X.

accuracy and precision are bought at a cost of increased set-up time, analysis time, and operator training. Three operating procedures have been studied in relation to the snow inventory problem, and will be discussed here.

Method 4: Single radiance-threshold level

This method is identical in principal to other radiance threshold or "density slicing" techniques such as use of iso-density photographic film, scanning densitometers, or certain digital computer programs. This type of processing normally is applied to data from MSS band 5 for snow measurements. All picture elements showing radiances greater than a certain threshold value chosen by the operator are classed as snow. The same threshold level is applied simultaneously to all portions of the scene. The method relies on the hope that the operator will be able to produce a mask that will yield an acceptable match to his visual interpretation of the snowpack.

This radiance procedure works well for some scenes, but in many other scenes it is annoyingly difficult to obtain agreement among operators regarding the "best" threshold setting. The uncertainty rapidly becomes worse as the operator lowers the threshold, trying to include the low-radiance snow--regions where the response is low because of tree cover, shadowing, or patchiness. The area-above-threshold tends to be a very sensitive function of the threshold setting in the region of the "Best Visual Estimate," BVE (Figure 3).

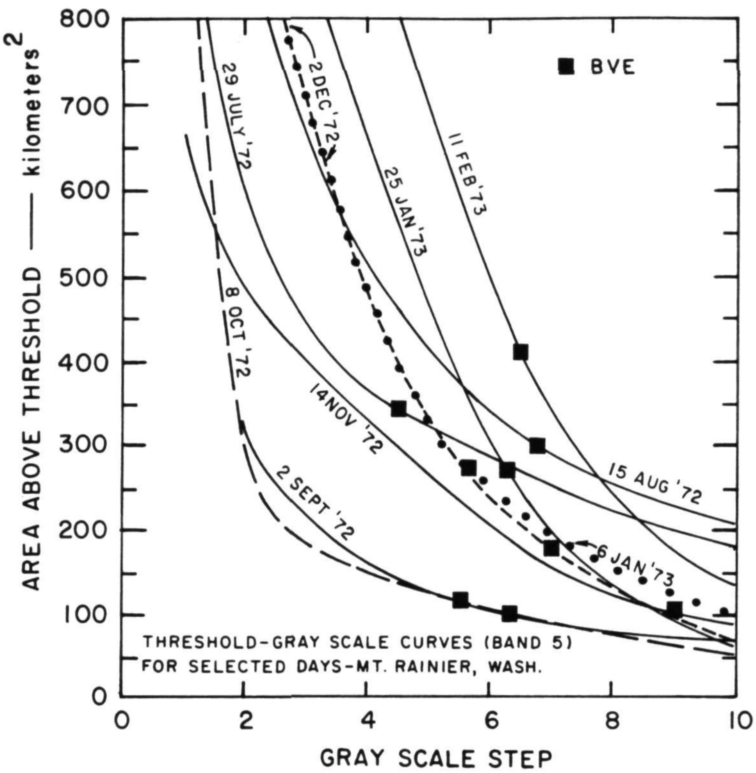

Fig. 3--Plots of radiance versus gray-scale step for several Mount Rainier, Washington, images. BVE is the best visual estimate of snow-covered area.

In addition to the operator decision problem, this high sensitivity at low radiances makes the system vulnerable to error from any of several instrumental difficulties that can cause slight differences in threshold performance for different regions of the picture. In images of late fall or early spring, when the sun angle is low and the snow extends well into the tree-covered regions, deviations of ± 30 percent of the snow-covered area are typical. Such problems are undoubtedly common to other "density slicing" techniques.

Method 5: Radiance-threshold setting locally edited by reference to altitude contours and other images

Again band 5 normally provides the source signal for the threshold circuitry. Through the use of the "scratch pad" memory it becomes possible to build up the binary snow mask in subbasin increments, each with its own threshold level rather than being constrained to accept some single compromise level. Particularly for difficult scenes, this improvement significantly reduces the inter-operator and repeat performance deviations in snowcover measurements. The effectiveness of this general approach can be further improved by always providing the operator with a good color display (even though the classification circuitry processes only one band) and by paying careful attention to details of how the various required display overlays--cursor, elevation contours, snow masks, etc.--are handled in order not to hide the subtle but important features in the image.

Assuming that the preparation of basin maps, contour overlays, and data sheets has been completed and that the operator is familiar with the region being evaluated, the incremental time required to analyze each new TV view (typically 2500 km^2) is a minimum of 20 minutes. This figure includes registering two spectral bands to each other and to a previously recorded sequence, creation of a binary mask depicting the snow theme, and readout of the mask data to the computer file.

This method is the currently preferred operating procedure.

Method 6: Two-band color-sensitive thematic extractions, locally edited as in method (5)

The ESIAC operating controls permit threshold setting or "slicing" (combined upper and lower-bound thresholds) operations to be performed simultaneously in two spectral bands and on the ratio of signals from the two bands. This provides a considerable degree of freedom in making the thematic mask responsive only to scene elements that correspond to specific regions of color space, as is plotted, for example, in a diagram of radiance in band 4 versus radiance in band 7 (Figure 4). By adjusting the system to respond to a diagonal band centered on the field of snow in Figure 4, snow in shadow can be counted without accepting responses from bright sunlit trees or from silty water. On the other hand, such an algorithm completely eliminates the whole gamut of snow-tree mixtures (Figure 5). Adjustments to include the snow-tree mixtures but not the trees result in frequent responses from rock and bare ground, and the resulting masks were found usually to be only slightly different from those obtained by the much simpler process of setting high-pass thresholds on band 4 or 5 alone. Note that a single-band threshold of the visible-band-radiance signal corresponds to counting everything in Figures 4 and 5 to the right of a vertical line that defines the threshold level.

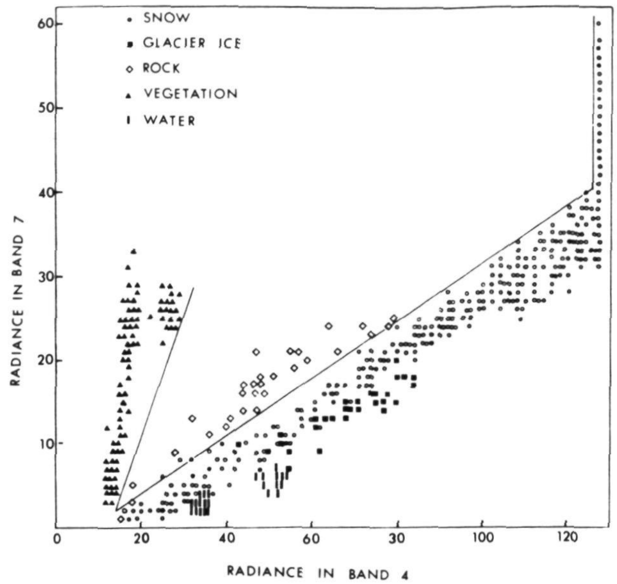

Fig. 4--Band 4/band 7, color-space plot showing five terrain types observed in the North Cascades, Washington. Note that the field of snow is clearly separated from the fields of other materials (except for glacier ice). The lines separate snow, rock, and vegetation. Each symbol represents one or more pixels.

The principal gain obtainable from operating with a tilted decision boundary instead of a vertical one lies in separating low-radiance snow--that which plots near the lower left corner of the color-space diagram--from vegetation and other materials. This separation is frequently easier to make on the basis of spatial distribution rather than spectral characteristics. An additional factor to be considered is that the low radiance corner of the diagram is a difficult region in which to work with an analog system. Signal-to-noise ratios are generally poorest, zero reference levels must be carefully watched, and photographic film is subject to "bleeding" and non-linear response.

There remains the possibility of combining bispectral classification with spatial and elevation information as was done with single-band data in method (5). It appears at this time, at least with an analog processing system, that the considerably greater attention required for both general system quality (color registration, equipment calibration, noise levels) and for adjustment of decision controls cannot be justified by expected improvements in accuracy and precision for operational snow area measurement. If the costs of digital preprocessing and input can be tolerated, then some variant of method (6) could be come extremely attractive.

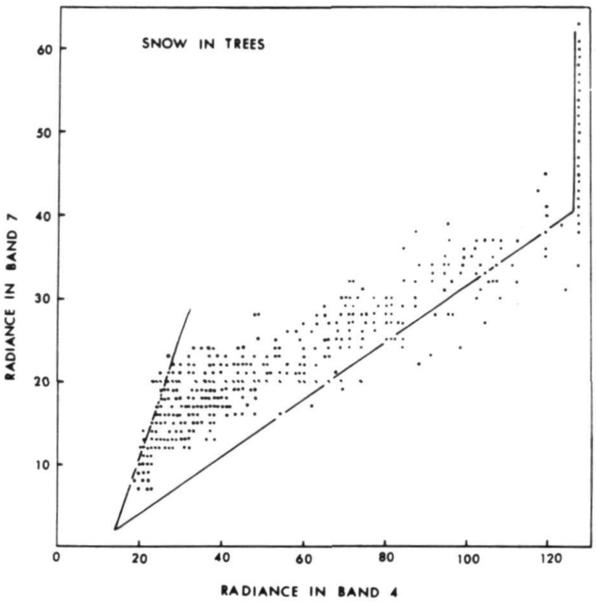

Fig. 5--Color-space plot showing snow in trees, similar to Figure 4. The lines are identical to those on Figure 4. Note that the field of snow in trees overlaps snow, vegetation, and the area between (including rock) as shown on Figure 4. Each dot represents one or more pixels.

Method 7: Digital pattern (spectral) recognition techniques

These powerful methods have been applied to snowcover measurement by Hoffer (1973) and by others. The method is most convenient when used in conjunction with an electronic console and standard pattern recognition programs. We employed only a modest computer terminal and simple two-dimensional programs to obtain a general impression of the advantages and disadvantages of the method. LANDSAT (ERTS) magnetic tapes were used of the North Cascades on May 12 and August 11, 1973.

An image denoting radiance levels of individual pixels was generated with a line printer, using characters to form an approximate grey scale. Drainage basin and training set boundaries were located on this and coded. Printouts were then obtained of two-dimensional radiance (color-space) plots for selected pairs of the 4 bands. Band 4 or 5 versus band 7 proved to be most useful for delineating the following terrain types: snow, snow and vegetation mixed, snow and rock mixed, glacier ice, water (silty and clear), rock, and vegetation (conifer forest, deciduous brush, alpine tundra). Snow could be clearly delineated from rock, water, and vegetation (Figure 4), but snow and vegetation mixed was not always clearly separated from rock (Figure 5). Two-dimensional fields were defined and a terrain map of the South Cascade Glacier area (part of the Cascade River drainage) was produced (Figure 6). A map of the same area was produced by visual photointerpretation; the snowline in part of the area (6.2 km^2) at the time of the satellite overpass was known from two cameras on the ground (Figure 7). Computer and visual recognition results are compared in Table 1. This shows a relatively high agreement in snow recognition (93.3 percent agreement,

Table 1--Summary of computer and visual recognition results for South Cascade Glacier area, for image of August 11, 1973. Numbers represent total pixels classified by each category and recognition method.

		Visual recognition						
		Snow	Ice	Water	Rock	Trees[1]	Tundra[2]	Total
Computer recognition	Snow	682	20	0	47	0	2	751
	Ice	3	67	5	12	0	0	87
	Water	0	1	40	1	0	0	42
	Rock	13	5	6	269	0	54	347
	Vegetation	0	0	0	0	3	2	5
	Snow and vegetation	0	0	0	0	0	18	18
	Rock and vegetation	1	0	0	51	1	150	203
	Snow and rock	32	6	0	42	0	3	83
Total		731	99	51	422	4	229	1,536

Performance on snow: 93.3%. Overall performance: 88.3%

1. Mature, large conifers.
2. Isolated trees, krummholz and alpine tundra intermixed with rock and soil.

equivalent to 3.2 percent error for the total area). Disagreement is attributed both to visual recognition error and to computer recognition error. In this case, with virtually no snow concealed under a forest canopy, the computer error is probably less than indicated above.

Fig. 6--Map of South Cascade Glacier area produced by computer recognition techniques. Black line is explained on Figure 7.

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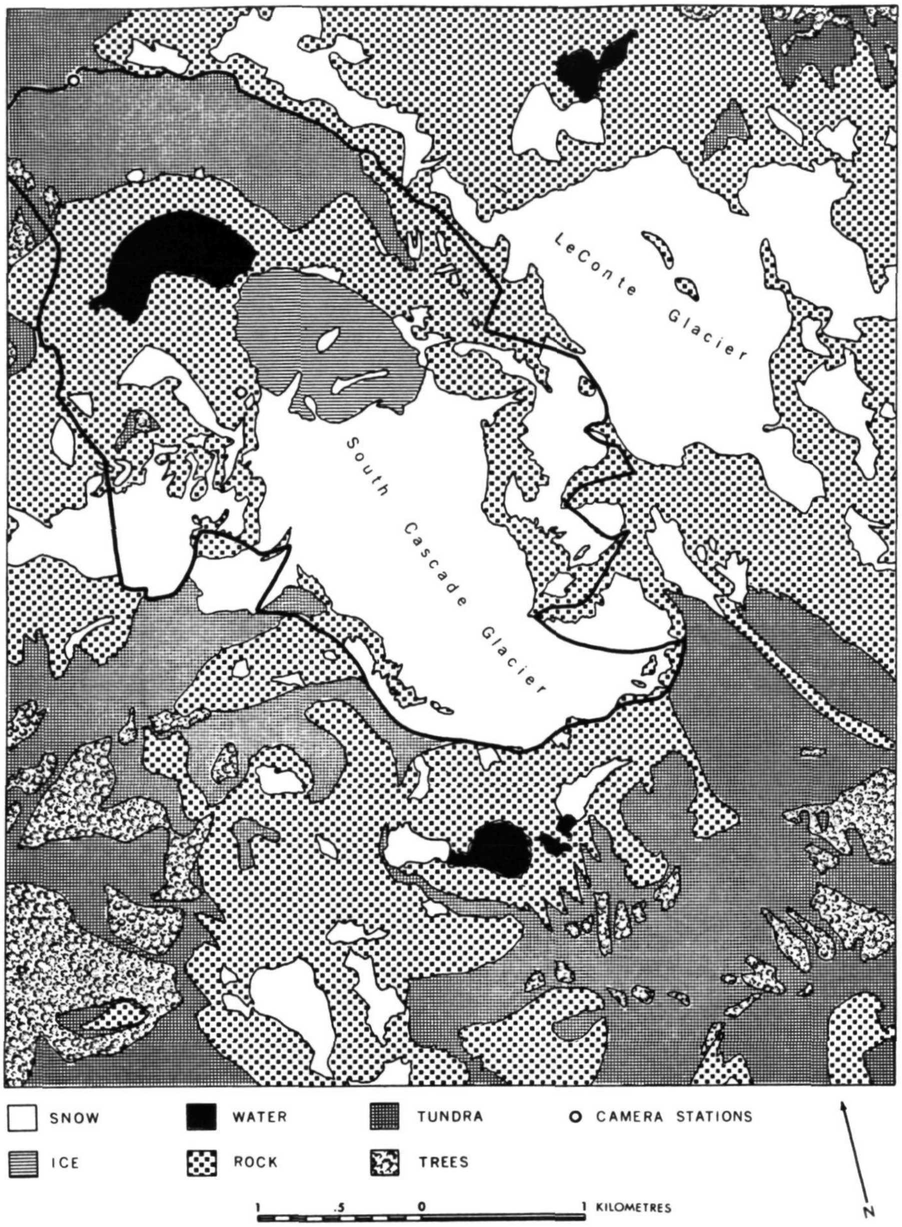

Fig. 7--Map of South Cascade Glacier produced by visual interpretation. The snowline is known only within the heavy black line, from photographs taken at two camera locations.

The program used to produce Figure 6 was then used to measure snow in the larger drainage basins of Cascade River (435 km^2) and Thunder Creek (272 km^2) for comparison with other methods.

COMPARISON OF METHODS

Precision

It is difficult to make other than generalized statements on the precision of different methods because of insufficient comparison data and the great flexibility inherent in each method. Also, it must be noted that for a given operator and method, the measurement error varies with the fraction of snow-covered area (Figure 8). With no snow, zero error is likely; with no snow-free ground the error also may equal or approach zero.

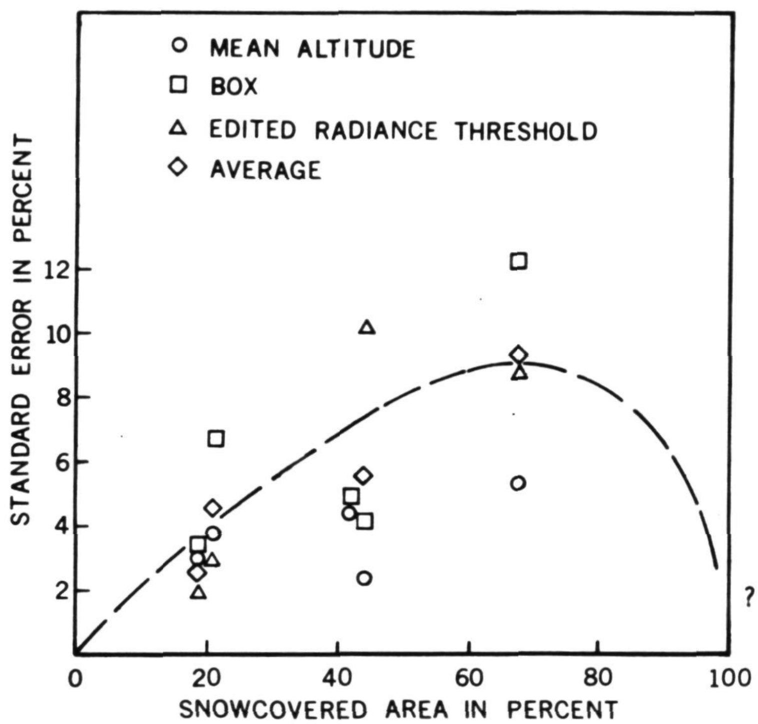

Fig. 8--Standard error for three methods as a function of snow-covered area. The dashed curve shows the probable shape of the curve, although sufficient data are not available to define it.

Results of the measurement of the five images of the Santiam Basin using three methods are shown in Table 2. The differences

Table 2--Comparison of mean altitude, box and radiance-threshold edited by altitude methods for Santiam Basin. N = number of observations (equal to or greater than the number of operators), $\bar{X}$ = mean snowcover, in percent of basin area, S = standard deviation of individual observations from the mean for that method, in percent of basin area.

	Mean altitude			Box			Edited radiance threshold			Unweighted average	
	N	$\bar{X}$	S	N	$\bar{X}$	S	N	$\bar{X}$	S	$\bar{X}$	S
Feb. 11, 1973	5	70.7	5.3	5	65.8	12.2	4	65.3	9.4	67.3	9.0
Apr. 6, 1973	5	52.4	2.4	5	45.5	4.2	7	33.3	10.2	43.7	5.6
Apr. 24, 1973	5	45.5	4.4	5	40.2	4.9	1	41.5	-	42.4	4.6
May 12, 1973	5	23.9	3.8	9	18.4	6.7	4	19.8	2.9	20.7	4.5
June 30, 1974	5	21.8	3.0	5	19.9	3.3	4	13.9	1.9	18.5	2.7

between methods are greatest for images with large snow-covered areas, as indicated in Figure 8, as would be expected because of the greater amount of snow in the low- and middle-altitude forests. The mean-altitude method over-measures snow because small bare patches at altitudes above the snowline are not included. The differences between the mean altitude and box methods ranged from about 6 percent in early melt season to about 2 percent at the end of the melt season. Perhaps this relation could be used to adjust the results.

Box, radiance-threshold, and digital techniques are compared for the North Cascades basins in Table 3. The digital method is thought to be most precise, but it cannot detect snow under a complete forest canopy. The radiance-threshold method may under-measure snow; in the April image it may fail to recognize snow in trees, and in August it fails to recognize snow in shadow. These problems also occur with the box method but the operator has more opportunity to use judgment in extending snow into areas where it is not visible. In deep shadows (especially on the August image) the digital method also cannot distinguish all terrain types unambiguously because of overlap at low radiance ratios.

Manual and electronic analyzer methods can also be compared by reference to the individual box data. Statistical data

Table 3--Comparison of box, radiance-threshold, and digital pixel-by-pixel results for Thunder Creek and Cascade River basins, in percent of basin area. Differences in values between the two adjacent basins for the radiance method may be due to misregistration of the basin boundary masks.

	Box	Radiance threshold	Digital, pixel by pixel			
	Snow	Snow	Snow	Snow + vegetation	Snow + rock	Total snow[1]
Thunder Creek						
May 12	60.6	42.3	50.8	6.4	4.0	59.2
August 11	13.3	12.3	15.0	1.1	3.2	17.7
Cascade River						
May 12	47.3	49.3	33.3	8.2	3.7	43.4
August 11	6.9	11.9	4.9	2.1	2.5	8.2
Total						
May 12	52.4	46.5	40.0	7.5	3.8	49.6
August 11	9.4	12.1	8.8	1.7	2.8	11.9

1. Computed as (snow) + (snow + vegetation) + 1/2 (snow + rock).

were derived for four measurements of the image shown in Figure 2. Comparison of these statistical printouts to a gridded original image confirms the subjective impression that the deviations from the mean are largest and vary the most in the mid-elevation snow-tree-mixture regions and around the fringes of the snowpack.

Speed and cost

No quantitative results are presented here for two reasons: speed of the manual methods is extremely sensitive to requirements for precision and to operator experience, and for more sophisticated methods the set-up or preprocessing operations vary enormously in speed depending on the equipment available and whether one has already accomplished much of the task using other images of the same drainage basin. Similarly, costs depend on many factors such as availability of equipment and the cost of labor. Thus only qualitative statements will be made.

The snowline-tracing method is slow in execution and thus requires appreciable labor cost; on the other hand virtually no expensive equipment is required. The mean-altitude method is fast and little equipment is required so its cost is low. The box method (when used to obtain high precision) is slow in execution but requires little equipment. The radiance-threshold method using an electronic analyzer is fast, but an expensive machine is involved. Edited radiance-threshold techniques require more operator and machine time and therefore are more expensive. Digital techniques are slow to average in speed depending on the equipment available for registering the image to a drainage basin boundary, and the costs are high to very high. The cost of the magnetic tapes, the cost of machine and labor for registering the image, and the computer time required for a four-dimensional pattern recognition program can be appreciable for a single measurement.

Ability to recognize snow in trees or shadow

Snow in a dense coniferous forest or in deep shadow is extremely difficult to recognize on a LANDSAT (ERTS) image either by eye or machine. Thus those methods which combine many kinds of information with interactive judgments by the operator are considered to be most efficient. An electronic analyzer utilizing either analog or digital multispectral input, with altitude contours and time-lapse sequences for editing, as well as the box technique using reference aids, can produce accurate results. Digital programs without interactive capability may be considerably less accurate. The mean-altitude method is relatively accurate. Simple radiance thresholds fail to detect snow in trees or in shadow.

Figure 9 shows a comparison of five methods plotted as percent of area snow-covered against altitude. Four of these curves were obtained by relating snowcover fraction in each box to the mean altitude of that box; this procedure is strictly correct only for very small boxes. The curve for the mean-altitude method was derived from the standard deviation of altitude obtained by an operator. Note that the curves for the radiance threshold edited by altitude and the box method have similar shapes; these are probably most nearly correct. The methods radiance-threshold and radiance-threshold edited without respect to altitude show some snow at very lot altitudes and less snow at high altitudes. This is undoubtedly because snow in trees and in shadow is not detected at high altitude and bright, snow-free areas are being recorded at low altitudes.

Supplemental data produced

Most streamflow models currently in use in the west require either snow-covered area or the snowline altitude, or both, as input or as a check on calculations. All seven methods can provide these data. More sophisticated models require additional data, such as the distribution of snowcover with altitude or in subbasins. By measuring snowcover in individual boxes, either manually or through the use of a console or computer program, it

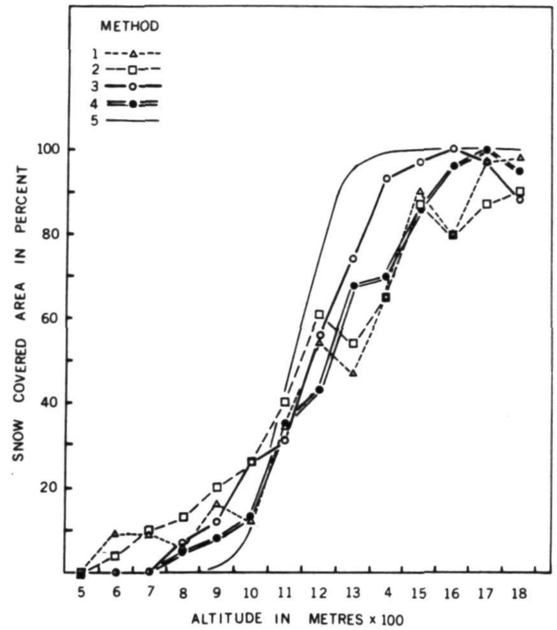

Fig. 9--Snow-covered area as a function of altitude for the Santiam Basin, April 6, 1973. These approach cumulative Gaussian distributions with standard deviation S. Method (1) used a simple radiance threshold; S = 300 m. Method (2) used a radiance-threshold edited without reference to altitude contours; S = 390 m. Method (3) used a radiance-threshold edited with reference to altitude contours; S = 230 m. Method (4) used box method; S = 250 m. Method (5) used mean-altitude method; S = 100 m..

is possible to provide this additional data. For instance, data can be produced showing the percent of snowcover as a function of altitude (Figure 9). These data can be used in energy-balance snowmelt models.

Summary of comparisons

Table 4 presents in summary form a qualitative comparison of the seven methods for precision, speed, cost, ability to recognize snow in trees, and supplemental data. This table represents only the views of the authors as derived mainly from the experiments on Santiam Basin images as discussed here. Other researchers using the same images or working in other areas may feel that the quality ratings should be reordered.

Several conclusions appear to be clear:

1. No method combines high precision with low costs.

Table 4--A listing of the seven methods by five important attributes. The quality distinctions given here apply only to the North Santiam, North Cascades, and similar images, as analyzed by the authors.

	Manual			Electronic, interactive analyzer			Digital computer
	(1) Plani-meter	(2) Mean alti-tude	(3) Box	(4) Radiance mask	(5) Radiance mask edited by altitude	(6) Radiance mask edited by color, altitude	(7) Pixel-by-pixel analysis
Precision	poor	average	good	poor	good	good	excellent
Speed	average	fast	average to fast	fast	average to fast	average	slow to average
Cost	average	low	average	low to average	high	high	high
Recognize snow in trees or in shadow?	fair	average	good	poor	good	excellent	good
Supplemen-tal data produced?	no	some	yes	yes	yes	yes	yes

2. The radiance-threshold method is inefficient for measuring snow in forested mountains.

3. The box method and use of a console with radiance threshold edited by altitude and other data appear to be most useful in that they are reasonably good in precision, speed, ability to recognize snow in trees or shadow, and produce supplemental data.

4. For fast inexpensive operation the mean-altitude method is probably best.

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